EXECUTIVE SUMMARY

Operable Unit 1 (OU 1) at Hill Air Force Base, Utah, is highly contaminated with a light nonaqueous phase liquid (LNAPL) containing a large variety of contaminants of environmental concern. Disposal sites at OU 1, including chemical disposal pits, landfills, and fire training areas, received large quantities of liquid wastes, which were periodically ignited. The waste mixture combined with the burning activities created a very complex NAPL that may contaminate an area (the source zones) as large nine acres. Groundwater contamination emanating from the OU 1 source zones has created two major dissolved-phase plumes, one of which impacts significant areas off-base. The primary contaminant of concern in the plumes is cis 1,2-dichloroethene (DCE).

The goal of the OU 1 Geosystem Model and Feasibility Simulations Project was to develop a comprehensive model of the LNAPL source zones and to use that model to investigate source removal options. A comprehensive geosystem model was built characterizing the physical-chemical properties of the OU 1 LNAPL in the laboratory, and integrating the results with existing site data and multi-phase fluid flow concepts into a model for OU 1. The objective was to obtain an understanding of the basic properties of the OU 1 LNAPL(s) and how these properties affect the migration and behavior of the source of contamination at this site. The resulting model serves as a tool used in the remedial decision-making process and a design basis for selected source removal actions.

At the initiation of this project, the potential impacts of proposed remedial operations in the OU 1 source zones on the behavior and migration of LNAPL could not be evaluated because the physico-chemical characteristics and the extent and distribution of the LNAPL were largely unknown. The first task completed for this project consisted of a desktop review and evaluation of existing site data, both in published literature and in reports by U.S. Air Force contractors. The resulting information was then utilized to build a geosystem model for OU 1. The second project task entailed characterizing samples of the OU 1 LNAPL so that this information could be added to the geosystem model, and conducting bench-scale experiments for preliminary remediation design parameters.

Once the character, migration, and behavior of OU 1 LNAPL was understood in the context of the site's hydrogeological setting, the final project task involved conducting numerical feasibility simulations to assess remediation strategies at OU 1. Numerical simulations were performed at two scales. Three-dimensional ground-water flow simulations conducted at the scale of the on-base source zone at OU 1 (the "site scale") were used to evaluate the impact of the de-watering trenches installed in the winter of 1999 to contain ground water in the source zones and recover LNAPL. Additional three-dimensional multi-phase fluid flow simulations were also conducted at a local scale (one trench segment) to evaluate the removal of LNAPL or LNAPL constituents through ground-water pumping, soil vapor extraction, and surfactant flooding. The effect of operating these trenches on the distribution of LNAPL, their effectiveness in recovering LNAPL, and their potential for use in future enhanced LNAPL removal operations were evaluated during this study.

Task 1 of the OU 1 Geosystem Project consisted of collecting and carefully reviewing all of the available information in existing literature and reports (the data assimilation task). Documents reviewed included work plans, remedial investigation/feasibility study reports, and design reports written by various contractors for the US Air Force (USAF), the Air Force Environmental Restoration Program Information Management System (ERPIMS), and published literature. The review focused on the physical setting of the site, including its stratigraphy, permeability structure, and hydrogeology, and on the characterization of the source zones, including the physical-chemical properties and distribution of the LNAPL. In addition, data gaps that need to be addressed to accurately characterize the OU 1 geosystem were identified during the assimilation and evaluation of the data.

The literature review found that the hydrogeologic and stratigraphic data available were adequate to establish a geosystem model for the OU 1 feasibility simulations. LNAPL saturations obtained from the NAPLANAL analyses of the chemical soil data in the OU 1 ERPIMS database ranged from 0.0 to 35 percent. The majority of the calculated saturations (93%) were under six percent. This is a significant observation considering that, as an approximation, the LNAPL can be considered to be immobile at saturations of less then six percent in the vadose zone and under 20 percent in the saturated zone. The spatial distribution of soil samples is sparse and therefore insufficient to properly characterize the volume and extent of an LNAPL source zone of this size. Finally, the LNAPL found in the various LNAPL zones of OU 1 is fairly variable in composition and distribution. These variations in the LNAPL properties can affect the efficiency of source zone remediation processes.

During the data evaluation phase of the project, a conceptual model of LNAPL migration and distribution at the site was formulated. Since liquid waste disposal has halted at OU 1, the volume of NAPL within the subsurface will change only to the degree that contaminants dissolve, volatilize or sorb into the aqueous, vapor, or solid phases, respectively. This change in volume with time is typically not very dramatic, particularly after the NAPL has been in the subsurface for years and the specific surface area of the NAPL has decreased as a result of dissolution and volatilization. It is important to note that, although the volume of LNAPL remains essentially the same, the amount of LNAPL existing, as either free-phase or residual LNAPL will change seasonally. The apparent LNAPL thickness measured in a monitoring well – an imperfect measure of the mobile LNAPL alone – can change rapidly with fluctuations in the water table. This can give the illusion of an "appearing" or "disappearing" LNAPL, although in reality the LNAPL is merely being redistributed vertically.

A limited amount of information was found on the character and distribution of the LNAPLs disposed of at OU 1. Most of these data were compiled during nine "side-by-side" treatability studies hosted in 1995-1996 by Hill AFB in order to evaluate innovative source removal options. Although the SERDP and AATDF studies conducted at OU 1 were field demonstrations of several emerging technologies designed to remove residual LNAPL, they generated only limited information on the site-specific physical and chemical properties of the LNAPL. These studies did however generate useful information that was compiled and synthesized into the OU 1 geosystem model.

A critically important issue that could not be addressed with the current site data is the occurrence of high DCE concentrations in the on-site and off-site ground water given the apparent absence of sufficient quantities of a parent compound. Since the 1,2-DCE, 1,1-DCE, and DCA have all been identified in ground water at OU 1, the potential parent NAPL for the DCE at OU 1 could be PCE, TCE, or TCA. Amounts of all three of these compounds identified in soil, water, and LNAPL samples collected at OU 1 are insufficient to be identified as the parents responsible for the DCE plume. There is no evidence to suggest that the parent compounds are no longer on site. Therefore, we caution against the conclusion that the resolution of this issue is no longer pressing.

Task 2 of the OU 1Geosystem Project involved conducting laboratory measurements and experiments to characterize the physico-chemical properties of OU 1 LNAPL and aquifer material, and to provide data necessary to assess various source removal technologies. The density, viscosity, interfacial tension, equivalent alkane carbon number and wettability of two samples of OU 1 LNAPL were measured to characterize the physico-chemical properties of the OU 1 LNAPL. The LNAPL viscosity measured for two samples varied between 34 and 239 cp which, is rather high and makes the LNAPL unsuitable for recovery by pumping and waterflooding. The density of the LNAPL was approximately 0.88 g/cc. The equivalent alkane carbon number (EACN) was approximately 6.01, which indicates that it is highly hydrophobic and relatively non-volatile. Based upon interfacial tension measurements, it was concluded that the LNAPL had a positive spreading coefficient under the ambient aquifer conditions, which enhanced its potential to spread both laterally and vertically under three-phase vadose zone conditions. Capillary desaturation experiments and the wettability experiments indicated that the LNAPL-aquifer was mixed to oil-wet. The mixed wetting nature was further confirmed by high residual LNAPL saturations on the order of 25% observed in soil from OU 1.

Using the LNAPL EACN, a custom surfactant formulation was designed to recover this hydrophobic and viscous LNAPL. This surfactant was designed after screening more than 35 surfactant formulations. The best formulation was found to be highly effective in soil column experiments and recovered 99.6% of the LNAPL after 4.4 pore volumes of throughput at a temperature of 65°C. At lower temperatures incomplete LNAPL recovery and a heavy "pitch-like" residue was observed after flooding the column. The elevated temperatures were required to recover virtually all components of the LNAPL leaving behind only 0.03 g of pitch which corresponded to a LNAPL saturation of 0.1%. The laboratory experiments indicate that a careful measurement of physico-chemical properties such as viscosity and EACN are necessary to select/design high performance surfactants for specific sites.

The final project task consisted of a simulation study of source removal alternatives conducted in two phases. The first phase included simulations to evaluate the hydraulic performance of the prescribed containment remedy. This system, recently constructed at OU 1, involves a series of extraction trenches and extraction wells designed to de-water the source zones at the site with the intention of containing contamination within the source zones and recovering LNAPL. These simulations, conducted using MODFLOW and the 3-dimensional multiphase, multi-component simulator UTCHEM, investigated the effect of various modes of system operation on de-watering of the aquifer, containment of contaminated ground water, and the process of LNAPL removal. The second simulation phase involved evaluating the feasibility of SEAR and SVE as source removal options. The source zone remediation alternatives evaluated were conceptual with respect to the level of engineering detail, because implementing such an option would require that the actual design work be conducted as a separate design project. SEAR simulations were run using UTCHEM, and AIRFLOW/SVE was used for the SVE feasibility simulations.

Simulations that implemented the design specifications outlined in the pre-design report (CH2M HILL, 1999) determined that the prescribed order of operation of the trenches would effectively de-water the OU 1 source zone and create gradients conducive to LNAPL recovery in the interior trench segments. However, because initial post-construction trench operations have not maintained water-levels in the perimeter segments at or above the prescribed elevation, the maximum production conditions under which the trenches were actually being operated were simulated as well. These simulations predict that the perimeter trench de-waters the S1 aquifer very rapidly and effectively and that the flow to the springs will probably cease almost completely. Simulations also indicate that seasonal increases in the recharge rate will have little impact on the site when it is in a de-watered condition. It is recommended that the site-wide MODFLOW model be updated with post-construction data and then used to optimize future trench operations. For example, because the gradients created by the current trench operations are not conducive to maximize future LNAPL recovery, it is recommended that the operation of the perimeter trench be studied to increase gradients to the interior trenches while preventing the potential for contaminated ground water to migrate off base.

Trench Segments U1-221 and U1-224 of perimeter Trench D, which is designed to contain contaminated ground water in the source area are critical to maintaining hydraulic control (containment) of the ground water in the OU 1 source zones. If Segment U1-221 fails, there is a possibility that contaminated ground-water flow to the western portion of the dissolved-phase plume and to the western springs (U1-307 and U1-306) will be reactivated. Likewise, if Segment U1-224 fails, it is probable that there will be an increased in flow to the eastern springs (U1-304, U1-303, and U1-318). These simulations also indicate that when the rest of the perimeter trench is functioning correctly, extraction operations at Trench Segment 216 are not as critical to hydraulic containment as there is little effect on the water-levels in the vicinity when it is not pumping.

In addition to determining the effect of de-watering the aquifer on the distribution and migration of LNAPL, the operational requirements to maximize trench effectiveness in recovering LNAPL and the potential use of the trenches in future enhanced source removal operations were also evaluated during the second phase of the simulation study. While the simulation results indicate that the trenches are effective in de-watering the OU 1 aquifer, it is concluded that the trenches are not very effective in recovering either mobile or residual LNAPL. It is predicted that the trenches will recover some LNAPL, but that the mass removed will be insignificant in relationship to the mass left behind in the source zones. The predominant factor controlling the LNAPL recovery and re-distribution process is the viscous nature of the OU 1 LNAPL, and significant production of LNAPL is not expected to occur during trench de-watering and containment operations. Less viscous LNAPL is likely to be found the furthest from the former CDP areas and will be recovered as a mobile phase more readily than more viscous LNAPL. However, the production of LNAPL can only occur after the water table near the trench has been drawn down to below the sump discharge of the drain line installed in the trench bottom.

According to the simulation predictions, the recoverable LNAPL will be produced at a low flow rate after the trenches have de-watered. The majority of the recoverable LNAPL will have been produced in a couple of months, although some trenches may continue to produce viscous LNAPL at extremely low flow rates for another couple of months of full LNAPL recovery operations. At the end of this period, it is anticipated little more than 10% of the LNAPL volume in the OU 1 source area will have been recovered.

Not only it is unlikely that there will be significant production of LNAPL during trench operations, but also the de-watering and containment will have an insignificant effect on the potential for mobilization and redistribution of LNAPL in most of the OU 1 source zone. One exception to this conclusion was inferred from a site-scale simulation of the ground-water flow in response to pumping the perimeter trench. The results of this simulation, combined with the observed recovery of LNAPL in Segment U1-221, indicate that pumping at the perimeter trench should continue at the maximum possible. If water levels are allowed to return back to those specified in the design (CH2MHill, 1999), loss of hydraulic control of contaminated ground water and any mobile LNAPL present in the vicinity of this segment is possible.

Simulation results indicate that SEAR is technically feasible for the removal of LNAPL from the OU 1 source zones. The key to the successful implementation of SEAR is to select a surfactant system that has favorable phase behavior properties. Given the viscous nature of the LNAPL, a surfactant system promoting solubilization is preferred for OU 1. Polymer can be added to overcome aquifer heterogeneity. The trenches installed at OU 1 can be utilized for extraction operations during SEAR provided that they are converted from pressure to rate control. Additional extraction wells and injection points may need to be placed at strategic locations so that the recovery of LNAPL can be optimized. The optimum SEAR injection and extraction system configuration will be dictated by the residual LNAPL saturation distribution in the source areas. The subsurface environment at OU 1 is complex, and it is necessary to characterize the subsurface well for SEAR. Should SEAR be selected for removing LNAPL at OU 1, additional simulations of the SEAR process using the OU 1 geosystem model will need to be carried out before it is implemented at the site.

Numerical simulations were also conducted to assess the feasibility of soil vapor extraction (SVE) at OU 1. Modeling efforts addressed three primary factors affecting SVE performance: the chemical composition of the contaminant; the vapor flow rates through the unsaturated zone; and the flow path of carrier vapors relative to the location of the contaminants. The chemical composition of the LNAPL at was found to be the limiting factor with respect to the efficacy of SVE. Simulations indicate that SVE will effective in removing the most volatile components from the LNAPL. The highly weathered nature of the LNAPL however, dictates that, even with closely-spaced wells (~30 ft), ideal vapor extraction rates (350 scfm), and long remediation times (10 years), less than 20% of the total LNAPL mass can be expected to be removed through SVE. Therefore, the use of SVE is not recommended as an effective means of reducing LNAPL saturations at OU 1. If the source of the aqueous DCE plume were located, SVE may be an effective means of removing the DCE and DCE parent compounds from the subsurface at that location, provided that the NAPL in question is trapped in the vadose zone.

The OU 1 site-scale model can be used to guide the future operation of the extraction trenches, and should become an integral part of the remediation optimization process. In order to accomplish this, the piezometers designed to monitor water levels in the vicinity of the trenches should be completed before trench segments are brought online, and the model should be re-calibrated as each of the segments become operational. Once calibrated, the simulated head distribution predicted for different operational schemes can be used to draw conclusions about the effectiveness of de-watering across the site. By changing the prescribed sump water levels in the model, the effects of changing operational specifications can be quickly investigated. For example, the impacts of pump maintenance or failure can be determined. Moreover, an analysis of the steady state water levels achieved with the extraction system in the long term may identify trenches which need not be pumped to maintain containment. These trenches could be taken offline so that wastewater treatment costs are minimized without impacting the performance of the system.

Another remediation process that can be optimized using the site-scale model is the Performance Verification Plan for OU 1. By analyzing the simulated distribution of heads under normal operating conditions, optimum locations for monitoring water levels and contaminants can be selected. Optimizing the monitoring network in this way prevents redundant and non-essential data from being collected and analyzed, and ensures that the critical locations to monitor for system performance are identified and sampled.

It is recommended that the extent of LNAPL (both mobile and residual) be adequately characterized before further evaluating and/or implementing LNAPL removal actions in the OU 1 source zones. Given the potentially large size of the LNAPL zone, it is neither cost-effective nor technically defensible to attempt to accomplish this with additional soil sampling. However, a laser-induced fluorescence (LIF) system be used to delineate the vertical and horizontal extent of LNAPL in the source zones. Although raw LIF data is qualitative in nature, it can be calibrated to quantify LNAPL saturations by correlating the tool’s response to saturations measured in a small test plot within the source zone.